Bharathidasan University

Tiruchirappalli – 620 024, Tamil Nadu, India

Programme: M. Sc. Physics

Course Title : Condensed Matter Physics

Code : 22PH303A

Unit I : Crystals and 2-D and 3-D Bravais lattices

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Introduction to Crystals and 2-D and 3-D Bravais lattices



Solid State

Matter -- Solid, liquid and gaseous states

Solid – Constituent of particles are fixed in position (atoms/ions/ molecules) except for thermal vibrations

Fluid – Material whose particles are in a state of constant translation motion

Classification of Solids

In terms of their degree and type of order

- Crystalline
- Semi-crystalline (poly crystalline)
- Non-crystalline (amorphous)

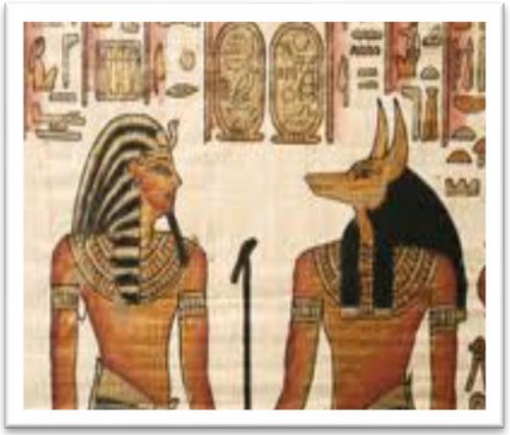
Crystals & Applications

Tools and weapons

Sapphire

Magical crystals

knives and spears



amulets

Crystals & Applications

Watches

Ornaments , necklace , Ring

dashboards of cars

LCD Projector

Crystals & Applications

Solar Panel

Medicine surgery

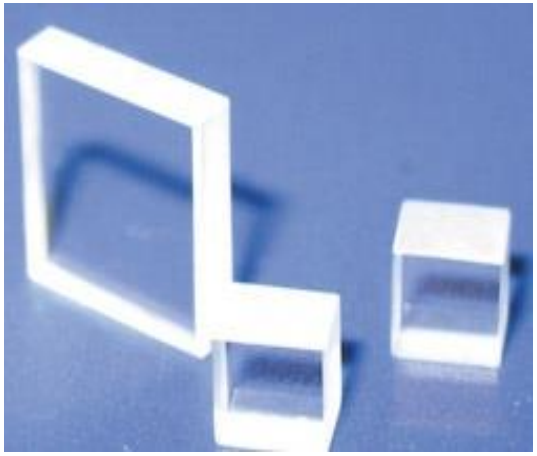
Satellite

Crystals

Snow

Quartz

NaCl



KDP

LBO

Ruby

Crystalline solid

Definition of a Crystal: A solid is considered a crystal if its constituent particles (atoms, ions, or molecules) are arranged in a three-dimensional periodic manner.

Formation of Crystals: Crystals are formed by the regular repetition of identical building blocks in three-dimensional space.

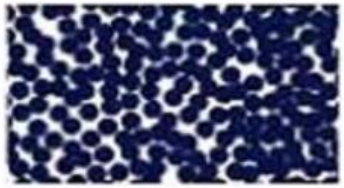
Characteristics of Crystals:

Optically smooth and plane faces.
Sharp, straight edges.
Well-defined interfacial angles.

Crystalline Structure

Non-crystalline (amorphous)

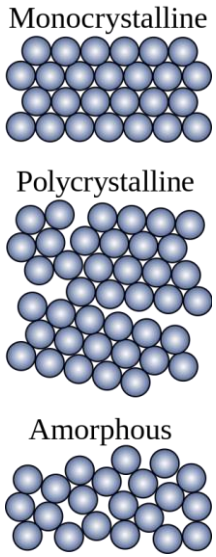
-A lacks a systematic atomic arrangement.



Amorphous Structure

Single crystal

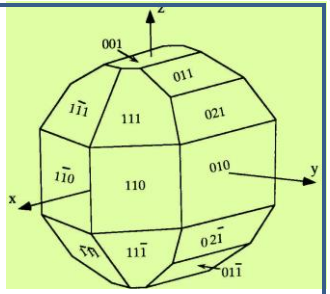
-Atoms arrangements in long-range order
-Anisotropy behavior
-Sharp melting point



Polycrystalline solids

-A solid consists of many crystallites oriented randomly and separated by well defined boundaries under the suitable conditions – they can be grown as single crystal.

Crystal



- A crystal form refers to a set of geometrically equivalent faces.
- The spatial arrangement of these faces is determined by the crystal symmetry.

Symmetry in Crystals:

- Symmetry describes the periodic repetition of structural features in a crystal.

Two general types of symmetry exist:

Translational Symmetry:

- Represents the periodic repetition of a motif across a length, area, or volume.

Point Symmetry:

- Represents the periodic repetition of a motif around a specific point.

Space lattice & Translation vectors

Crystal Structure:

- Constituent particles (atoms, ions, or molecules) are arranged in a three-dimensional (3D) periodic manner.

- Bravais introduced the concept of the space lattice to describe periodicity.

Formation of a Space Lattice: An object is translated by a finite distance, **'a'**, and systematically repeated along the three crystallographic directions: **x, y, and z**. This process results in a three-dimensional array of points, forming a **space lattice**.

Lattice Construction: Each repeated object in the array is replaced with a **point**, and the collection of these points is called a **lattice**.

Types of Lattices Based on Dimensions:

1D Lattice: Defined by a linear periodic translation.

2D Lattice: Defined by two non-collinear translations, forming a plane lattice.

3D Lattice:Defined by three non-coplanar translations, forming a space lattice.

Space lattice & Translation vectors

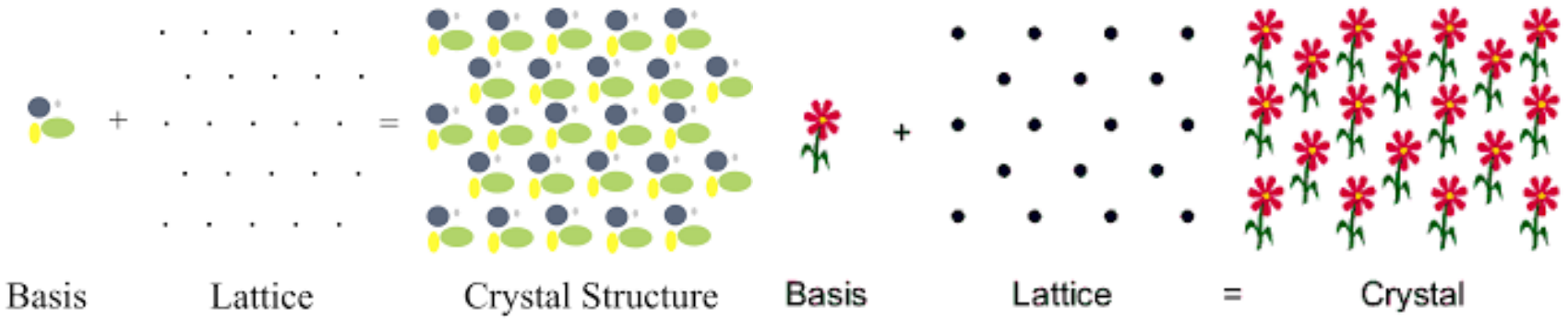
A space lattice can be visualized using three **translation vectors**: ***a***, ***b***, and ***c***.

The three **translation directions**, **x**, **y**, and **z**, are referred to as the **crystallographic axes**. By considering any lattice point as the origin, the location of any other lattice point within the lattice can be mathematically described as: $\mathbf{T = n_1a + n_2b + n_3c}$

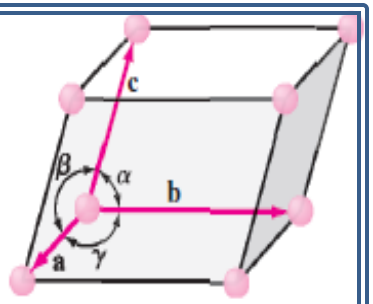
Crystal Structure

Properties of solids depend upon crystal structure and bonding force.

Lattice + Basis ---------- Crystal structure



Unit cell



Crystals are composed of an infinite number of **unit cells**.

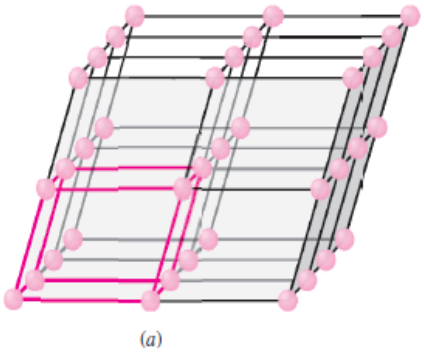
The **unit cell** is the simplest parallelepiped formed by the primitive translation operation, **T**.

It is the smallest repeating unit of a crystal that generates the entire crystal structure when repeated in **3D space.**

A unit cell is defined by six parameters:

Three axes lengths: ***a***, ***b***, and ***c***.

Three inter-axial angles: **α**, **β**, and **γ**.



Crystal lattice

A crystal lattice is a conceptual 3D grid system where every point (or node) has an identical environment to that of all other points or nodes in the lattice.

Lattice and unit cell

A specified **motif** is translated linearly and repeated multiple times to form a lattice.

A **lattice** is an array of points that defines a repeated spatial entity called a **unit cell**.

The **unit cell** is the smallest repeating unit that can be replicated in three dimensions to construct the entire lattice.

Lattice Points:
The **corners** of the unit cell serve as points that are repeated to form the lattice array. These repeated points are referred to as **lattice points**.

Types of Lattices: In two dimensions, only **five different lattices** can be formed through translation.

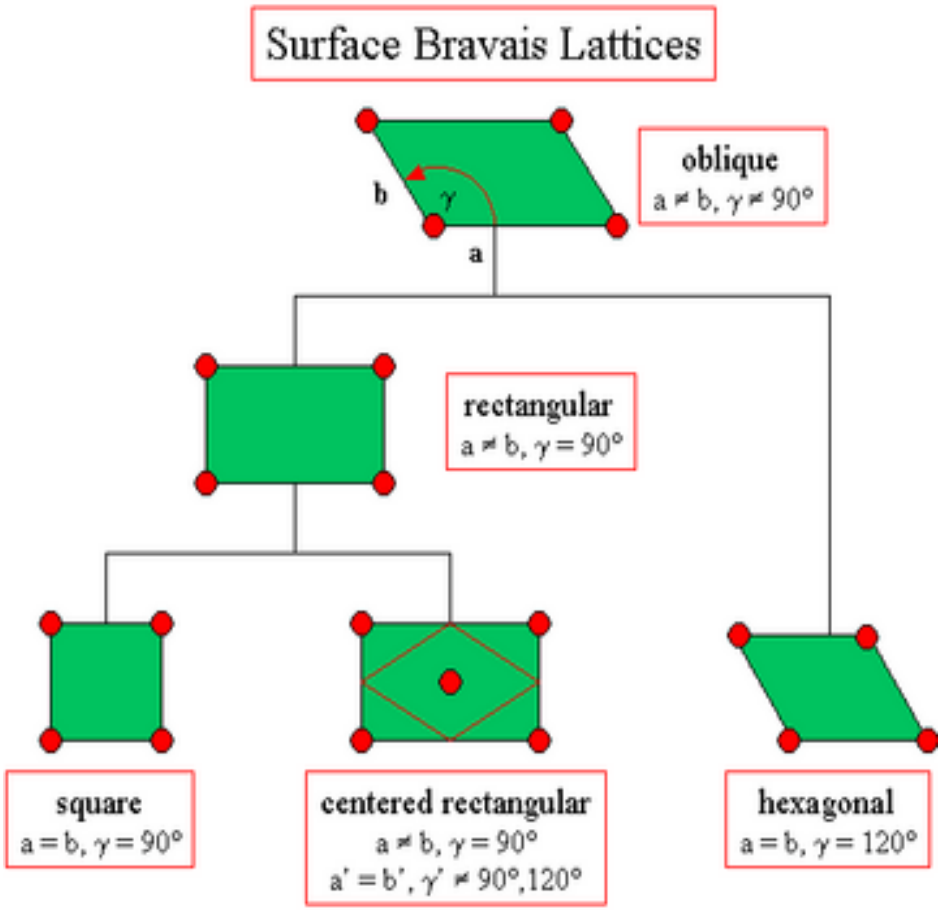
Only fourteen different lattices can be constructed in three-dimensional space, as established by French crystallographer **Auguste Bravais** (1811-1863). These **fourteen distinct lattice structures** are known as the **Bravais lattices**.

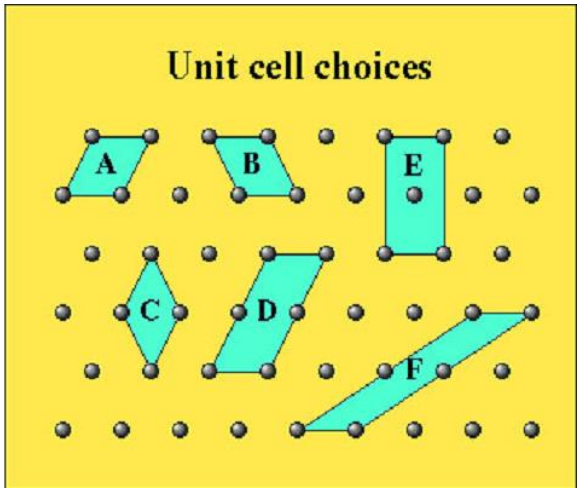
Bravais lattices

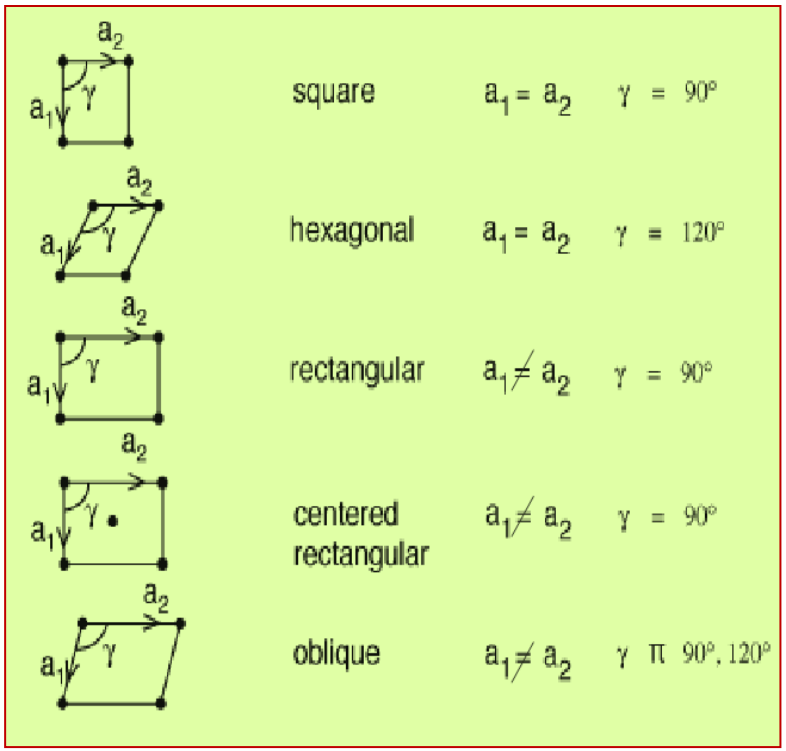
Auguste Bravais
(1811-1863)

- In 1848, Auguste Bravais demonstrated that in a 3-dimensional system there are fourteen possible lattices
- A Bravais lattice is an infinite array of discrete points with identical environment.
- Seven crystal systems + four lattice centering types = 14 Bravais lattices
- Lattices are characterized by translation symmetry

2D Bravais Lattices







3D Bravais lattices

Bravais Lattices and Crystal Systems:

The fourteen Bravais lattices are categorized into seven crystal systems: Cubic, Tetragonal, Orthorhombic, Monoclinic, Triclinic, Trigonal, Hexagonal

The Bravais lattices can be further classified into four types based on their structure:

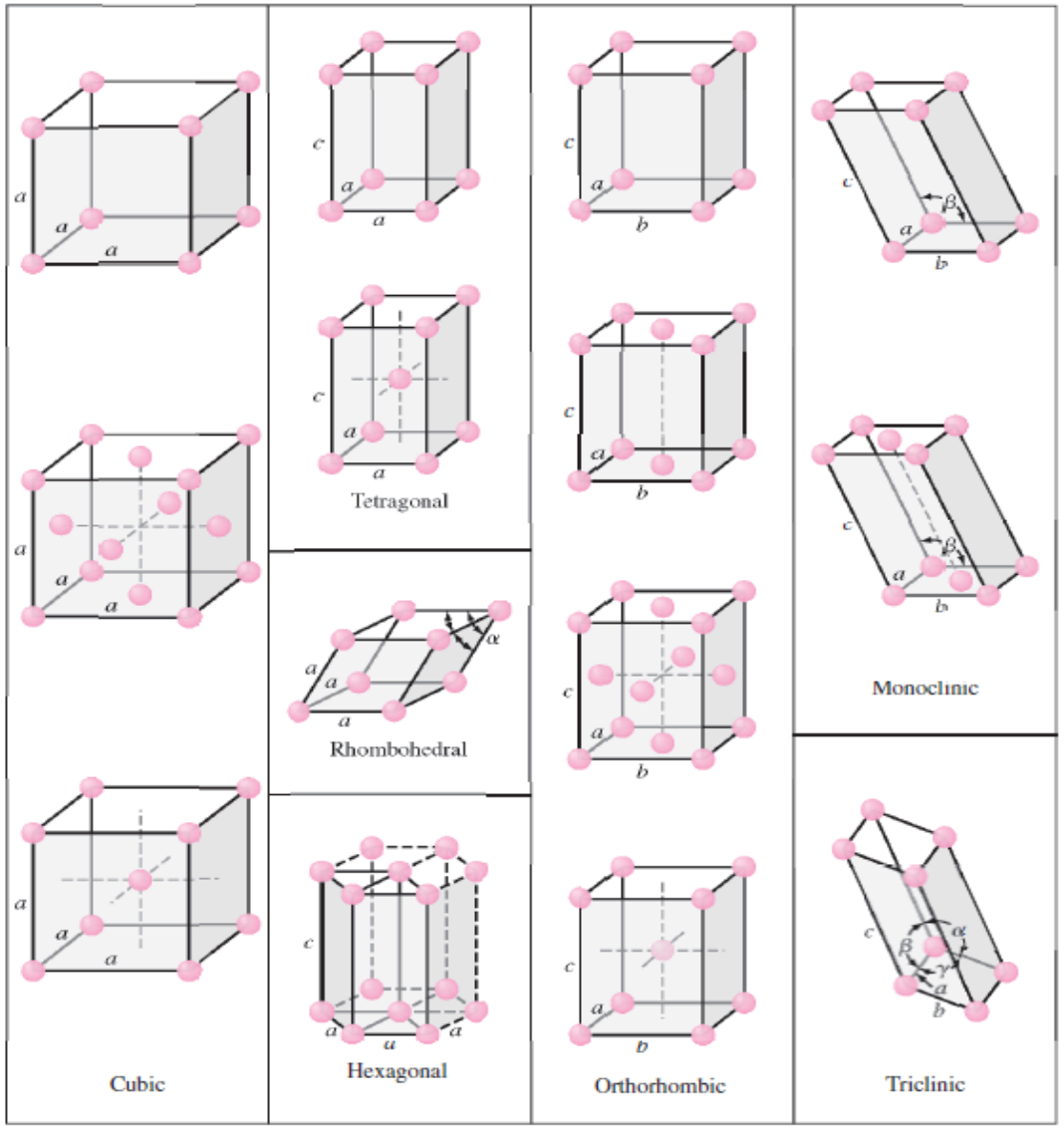
- Primitive Lattice: Contains only lattice points at each corner of the unit cell.
- Body-Centered Lattice: Includes lattice points at each corner of the unit cell, plus one lattice point at the center of the unit cell.
- Face-Centered Lattice: Has lattice points at each corner of the unit cell, and also at the centers of one or more faces
- Base-Centered Lattice : Either at the centers of one pair of faces or all three pairs of faces.

Four lattice centering types

No.	Type	Description
1	Primitive	Lattice points on corners only. Symbol: P.
2	Base Centered	Lattice points on corners as well as centered on faces. Symbols: A (bc faces); B (ac faces); C (ab faces).
3	All-Face Centered	Lattice points on corners as well as in the centers of all faces. Symbol: F.
4	Body-Centered	Lattice points on corners as well as in the center of the unit cell body. Symbol: I.

Crystal system	Axial lengths and interaxial angles	Space lattice
Cubic	Three equal axes at right angles $a = b = c, \alpha = \beta = \gamma = 90^\circ$	Simple cubic Body-centered cubic Face-centered cubic
Tetragonal	Three axes at right angles, two equal $a = b \neq c, \alpha = \beta = \gamma = 90^\circ$	Simple tetragonal Body-centered tetragonal
Orthorhombic	Three unequal axes at right angles $a \neq b \neq c, \alpha = \beta = \gamma = 90^\circ$	Simple orthorhombic Body-centered orthorhombic Base-centered orthorhombic Face-centered orthorhombic
Rhombohedral	Three equal axes, equally inclined $a = b = c, \alpha = \beta = \gamma \neq 90^\circ$	Simple rhombohedral
Hexagonal	Two equal axes at 120°, third axis at right angles $a = b \neq c, \alpha = \beta = 90^\circ,$ $\gamma = 120^\circ$	Simple hexagonal
Monoclinic	Three unequal axes, one pair not at right angles $a \neq b \neq c, \alpha = \gamma = 90^\circ \neq \beta$	Simple monoclinic Base-centered monoclinic
Triclinic	Three unequal axes, unequally inclined and none at right angles $a \neq b \neq c, \alpha \neq \beta \neq \gamma \neq 90^\circ$	Simple triclinic

The 14 Bravais conventional unit cells grouped according to crystal system. The dots indicate lattice points that, when located on faces or at corners, are shared by other identical lattice unit cells.



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